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Technical Reference

Gaseous System Technical Information

Introduction

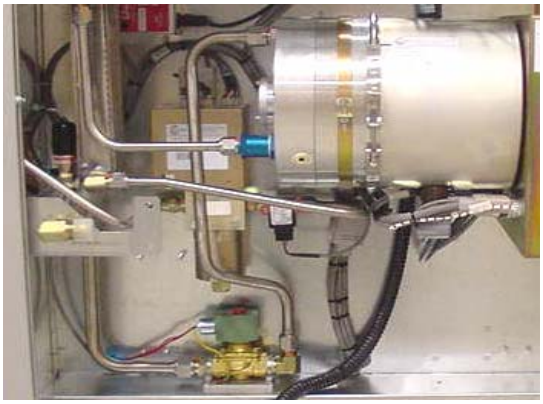
This document provides product information for Capstone Turbine Corporation® MicroTurbines operating on approved low-pressure and high-pressure gaseous fuels. Fuels can vary in physical composition, higher heating (HHV) value and contaminant limitations. See the MicroTurbine Fuel Requirements Technical Reference 410002 for further details.

Fuel system types covered in this document are: High/Low Pressure Natural Gas (HPNG/LPNG), Landfill/Digester or Biogas, and Sour Gas. These types are collectively referred to as: High Pressure and Low Pressure Natural Gas systems. High Pressure Natural Gas descriptions apply to both stationary and hybrid electric vehicle (HEV) models.

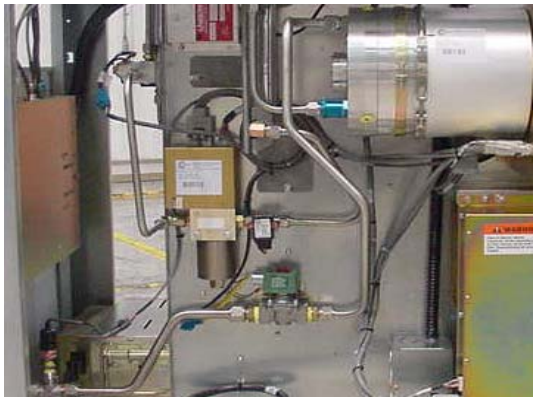
Model C30 Natural Gas systems are available in several packages: standard, open, industrial or Small Industrial Package (SIP) models. Model C60 systems are available only in the Large Industrial Package (LIP).

Available configurations for low-pressure and high-pressure systems are shown below:

Standard or Open Package

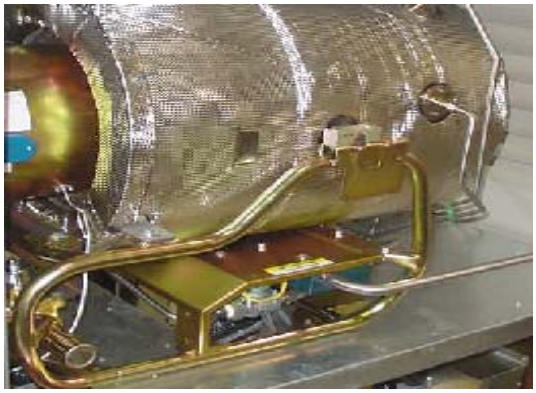


Industrial Package



Small Industrial Package (SIP) or HEV

Large Industrial Package (LIP) – C60 only



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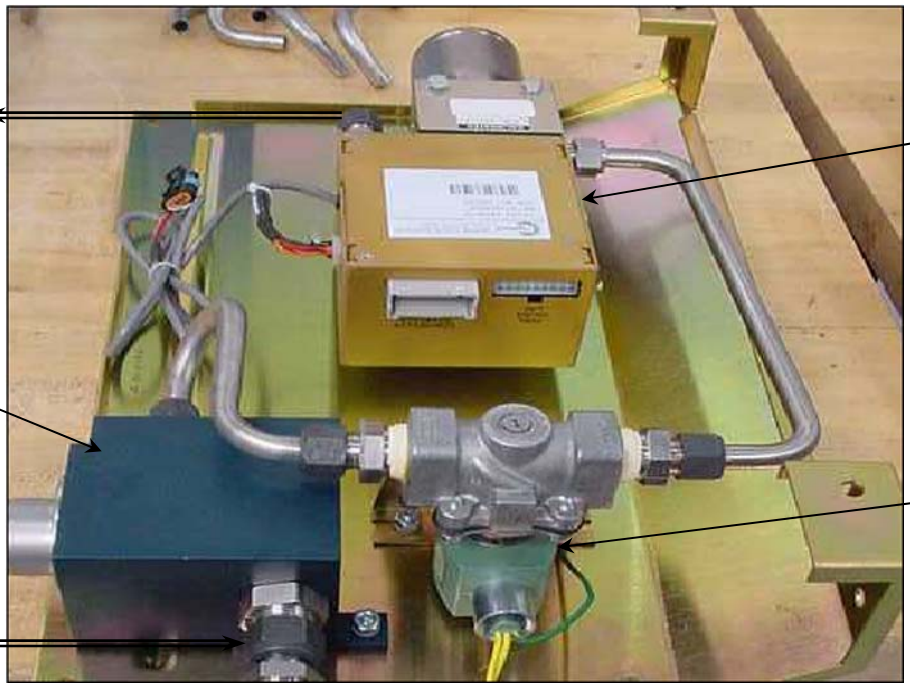
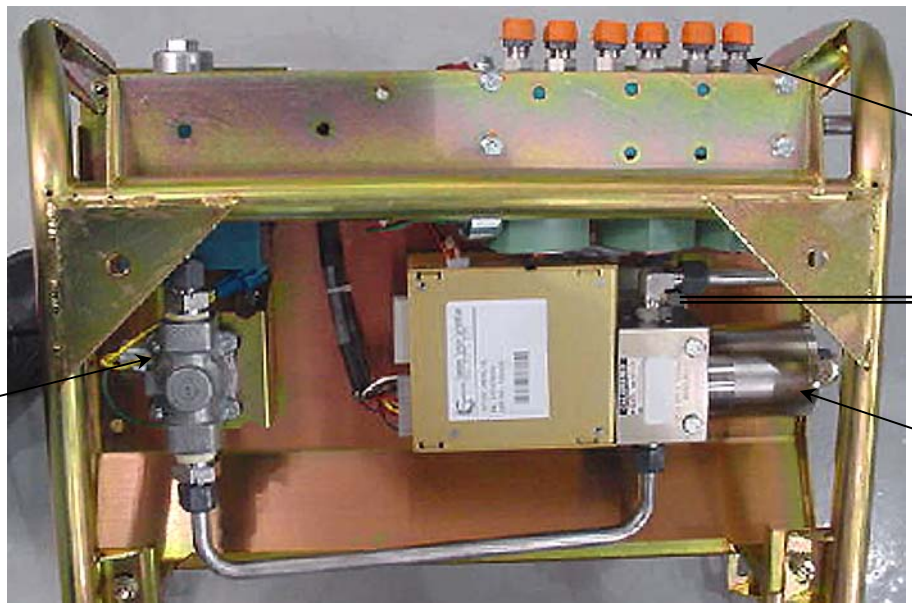
High Pressure Gas System Components

High-pressure gaseous fuel components (C60 – Large Industrial Package shown) are identified below:

NOTE	Component descriptions are provided in the Components Description Technical Reference Manual (410012).



Top View



Side View

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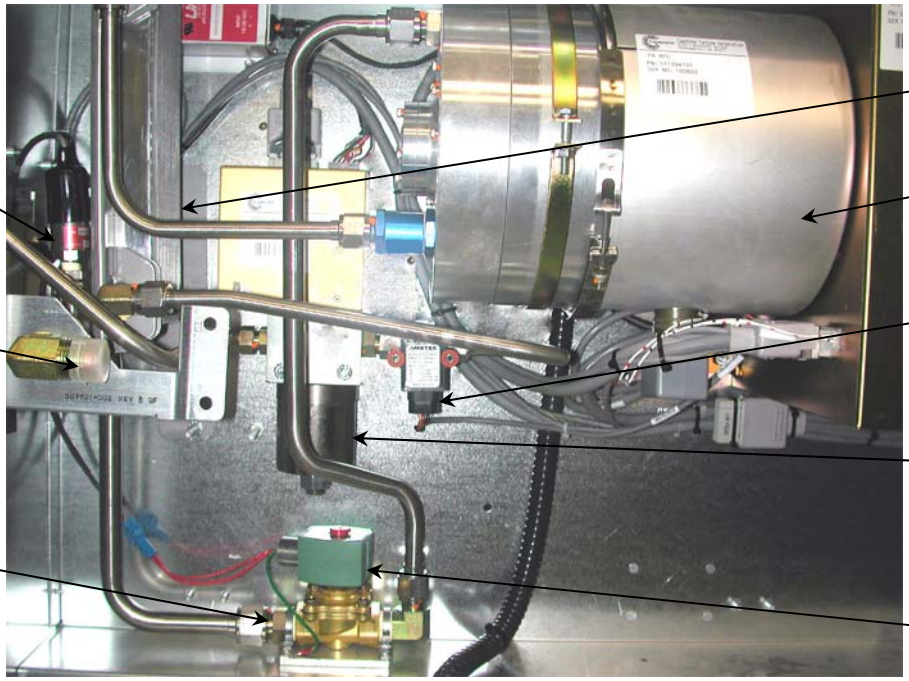
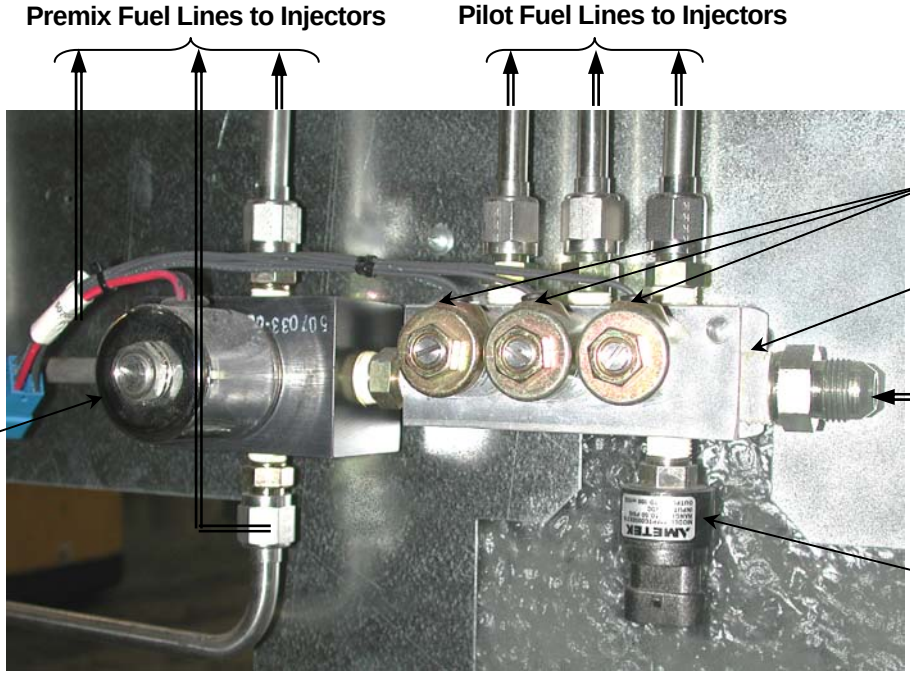
Low Pressure Gas System Components

Low-pressure fuel system components (C30 - Standard Package shown) are identified below:

NOTE	Component descriptions are provided in the Components Description Technical Reference Manual (410012).





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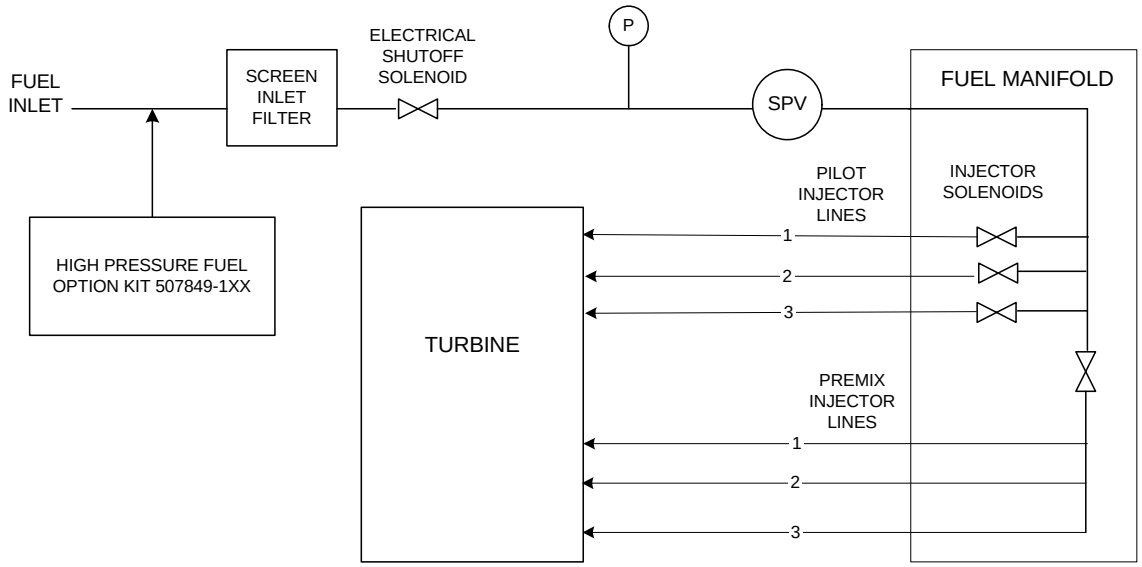
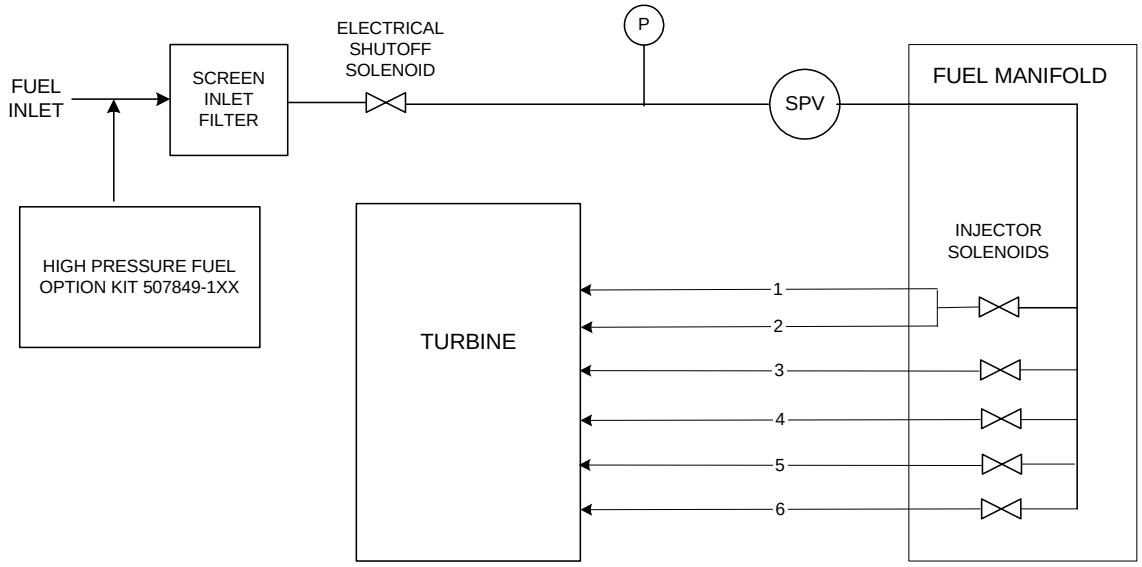
System Operation

High-Pressure Natural Gas

A block diagram of a Model C30 high-pressure natural gas fuel system is shown below.



A block diagram of a Model C60 high-pressure natural gas fuel system is shown below.



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Natural gas enters the MicroTurbine package inlet and is passed through a gaseous filtering element to eliminate particulates from the fuel. Filtered fuel flows through an electrical fuel shutoff valve, which is commanded on for operation. The fuel shutoff valve protects the MicroTurbine by cutting off fuel to the MicroTurbine in case of a fault condition.

The Smart Proportional Valve (SPV) controls fuel flow into the fuel manifold, and subsequently into the injectors, based on a software-controlled position command. Maximum fuel supply to the injectors is delivered at a command of 80 percent valve position.

The fuel manifold contains electrically controlled solenoids, which directs fuel flow through the injectors. The number of injectors depends on the MicroTurbine model. On a Model C30, four solenoids control fuel flow into the three injectors – there are three pilot solenoids and a single premix solenoid. On a Model C60, there are five solenoids - one solenoid activates injectors 1 and 2, the others individually turn on injectors 3, 4, 5 and 6.

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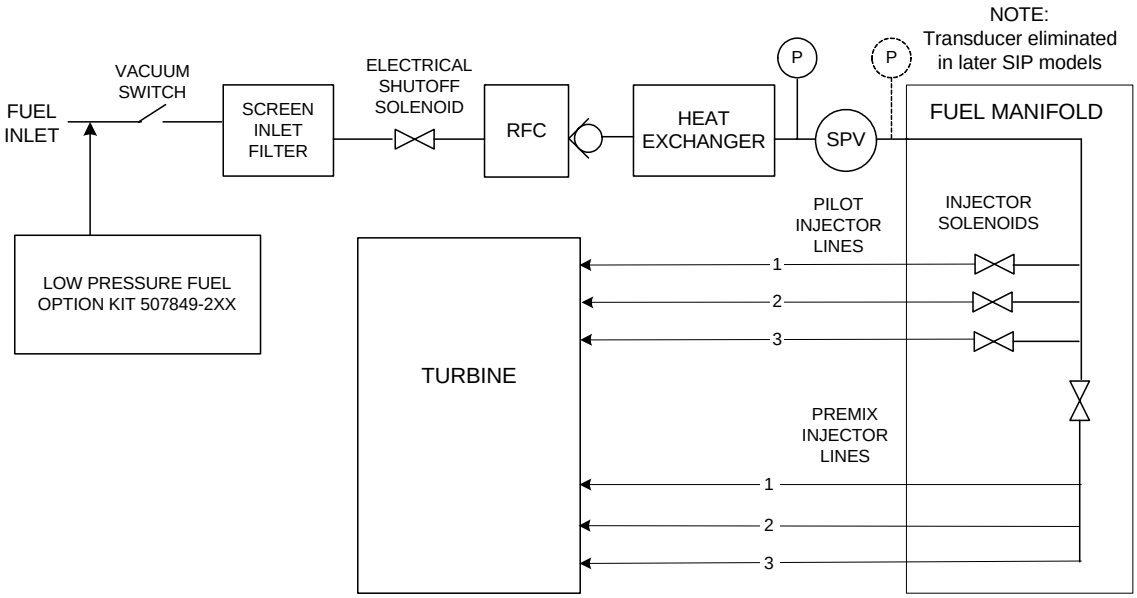
Low Pressure Natural Gas

A block diagram of a Model C30 low-pressure natural gas system is shown below (dotted line for pressure transducer indicates this component has been eliminated in later models):



Natural gas entering the MicroTurbine is monitored for fuel pressure by a protective vacuum (pressure) switch. If close to vacuum conditions are detected, operation ceases and a 3024 LOW FUEL PRESSURE fault is reported. An inlet screen filter to the electrical shutoff valve restricts larger fuel particulates from clogging the system. If a fault condition exists, the electrical fuel shutoff valve closes to stop fuel flow into the MicroTurbine; otherwise it is commanded open to maintain fuel flow to the MicroTurbine during system operation.

The Foil Bearing Rotary Flow Compressor (FB-RFC) compresses the low-pressure fuel supply up to the required fuel system operating pressure. The RFC operates as a gas compressor at low fuel rates and a flow control device at high fuel flow rates. The compressed high-temperature gas from the RFC is pressure monitored and cooled via a heat exchanger before entering the SPV.

The SPV and RFC work together to control fuel flow. At low power levels, the RFC operates at a constant speed and the controlling orifice in the SPV meters fuel. At high power levels, the SPV is commanded to a maximum open position, and the flow is metered by varying the speed of the RFC.

A vacuum switch is present on the gas inlet to the fuel system to ensure that the fuel pressure is nominally maintained above ambient pressure conditions. This protects the RFC from operating under gas-starved conditions that could damage the foil bearings (i.e., the gas supply is shut off during system operation).

The fuel manifold contains electrically-controlled solenoids, which direct injector fuel flow. On earlier low-pressure configurations, exit pressure is monitored through a transducer mounted on the fuel manifold. In later models (SIP configuration), this transducer has been eliminated.

Low Pressure natural gas systems may require additional considerations or fuel option kits to deal with inlet fuel pressures above or below nominal pressures.

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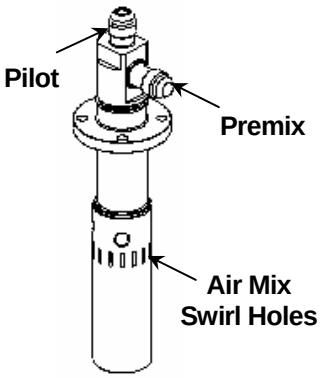
Injector Operation

Model C30

The Model C30 MicroTurbine utilizes three pilot injector solenoids (1, 2 and 3), and a single premix solenoid to control fuel flow to the engine.

Each injector delivers fuel from two points of entry – directly from the pilot tube, or through the premix tube. The pilot tubes supply fuel directly into the combustion chamber, mixing with air from the recuperator. The premix tubes utilize air from the recuperator through swirl holes in the injector, prior to entering the combustion chamber.



C30 Injector

Injector operation changes at different power levels (ISO corrected generator power). Power levels for each injector switch point decrease by approximately 2 kW due to hysterisis effects during offloading.

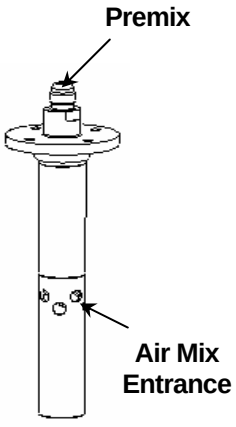
- Below 7 kW, the MicroTurbine operates with a single pilot injector.
- From 7 kW to 22 kW, all three pilot injectors are switched on.
- Above 22 kW, all three pilot solenoids are turned off, and the premix solenoid is switched on.

To increase flame stability with medium or low BTU content fuels, the sequencing of the fuel solenoids changes based on the BTU content value selected. For a BTU content setting of medium, the system will light on three pilot injectors and switch to premix mode as noted above. Medium BTU systems will never operate in single pilot mode. For a BTU content setting of low, the system will light and always operate in premix mode. The pilot solenoids will never be used. Refer to the *BTU Content Switch* section for information on this setting.

Model C60

The Model C60 MicroTurbine utilizes five injector solenoids, located on the fuel manifold for controlling fuel flow into six injector ports of the engine.

Injectors 1 and 2 are always on and are controlled by a single solenoid. Injectors 3 thru 6 are operated by separately controlled solenoids. The C60 always operates in premix mode.



C60 Injector

Injector operation changes at different power levels (ISO corrected generator power). Power levels for each injector switch point decrease by approximately 3 kW due to hysterisis effects during offloading.

- The MicroTurbine initially lights using injectors 1 and 2 (one solenoid operates both injectors).
- Above 15 kW, third injector turns on (turns off at ~12 kW).
- Above 26 kW, fourth injector turns on (turns off at ~23 kW).
- Above 43 kW, fifth injector turns on (turns off at ~40 kW).
- Above 54 kW, sixth injector turns on, and all six are in operation (turns off at ~51 kW).

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Fuel Selection and Utilization

Allowable Fuels

The MicroTurbine is capable of burning a wide variety of gaseous fuels to generate electrical power. A Model C30 low BTU fuel system option can provide for operation from 13,000 (350) to 26,100 kj/NM3 (760 BTU/scf). This option requires higher fuel gas supply pressures and is not available in combination with the low-pressure fuel system. For more information regarding fuels allowed on different system configurations, refer to the MicroTurbine Fuel Requirements Technical Reference (410002).

Specifying Fuel Characteristics

As shipped, the MicroTurbine is configured for standard natural gas fuel. If gaseous fuels with physical characteristics other than standard natural gas fuel are used, information on the physical characteristics of these fuels may be entered into the system to ensure that:

a) Flame stability margins are maintained, and

b) NO_X exhaust emissions are minimized.

Fuel Indices

The MicroTurbine incorporates fuel gas physical characteristics into the control functions in the form of the fuel indices defined as follows:

NOTE	Index parameters must meet requirements stated in the MicroTurbine Fuel Requirements Technical Reference (410002).

$$FUELI1 = SG * \left(\frac{1327}{HHV_{vol}}\right)^2$$

FUELI2 - (Not currently used on gaseous fuel systems)

where:

SG = fuel gas specific gravity, with respect to air

HHV_{vol} = fuel gas higher heating value, BTU/scf

Fuel Index 1 (FUELI1) is a parameter related to the fuel density and energy content. If the FUELI1 parameter entered differs by more than 15 percent from the index for the actual fuel being burned, nuisance flameout or over-temperature faults may occur.

Setting adjustments may be entered through the display panel keypad, or remotely, through the user interface port (UIP) upon commissioning of the system. Table 1 shows the values of FUELI1 for common fuel gases.

Fuel Index 2 (FUELI2) is not currently used on gaseous fuel systems.

The specific gravity (SG) and higher heating value (HHV_{vol}) of commercial natural gas fuels may be obtained from the local natural gas supplier. Gas chromatographic analyses of non-commercial fuel gases commonly report calculated specific gravity and higher heating value.

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BTU Content Setting

As the energy content of fuel gas decreases, so does flame stability. To maintain acceptable flame stability below 970 BTU/scf HHV on Landfill /Digester and Sour Gas Model C30 systems, adjustments in fuel system sequencing are required. The BTU Content switch enables these adjustments.

System Settings Menu	Parameter Description (BTU/scf HHV)	Format	Default
BTU Content	Normal for 970 – 2516 Medium for 760 – 970 Low for 350 – 760	Normal Medium Low	Normal
Variable BTU <FUELI1>	FUELI1 as defined above	0.10 – 99.99	1.00

Table 1. Fuel Indices for Common Fuel Gases

Fuel Name	Specific Gravity (w/ respect to air)	HHVvol High Heating Value (BTU/scf)	FUELI1	BTU Content Switch
Natural Gas Baseline	0.613	1,039	1.00	Normal
Methane	0.554	1,013	0.95	Normal
Ethane	1.049	1,792	0.58	Normal
Propane	1.562	2,592	0.41	Normal
Digester gas (max)	0.959	672	3.74	Low
Digester gas (avg)	0.909	607	4.34	Low
Digester gas (min)	0.862	363	11.49	Low
Landfill gas (max)	1.004	674	3.90	Low
Landfill gas (avg)	0.973	496	6.96	Low
Landfill gas (min)	0.995	355	13.94	Low

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If values of the specific gravity and/or higher heating value are not available, they may be calculated from the gas composition. A sample calculation is provided in Table 2.

Table 2. Sample Calculation, Oil Wellhead Gas

1 Gas Component	2 Symbol	3 (SG) (WRT Air)	4 HHV_{vol} (BTU/Scf)	5 Concentration (Volume %)	6 (SG) (Col 3 * Col 5)	7 HHV_{vol} (Col 4 *Col 5)
Hydrogen	H_2	0.0695	325	-	-	-
Carbon Monoxide	CO	0.9672	322	-	-	-
Methane	CH_4	0.5541	1013	61%	0.338	618
Ethane	C_2H_6	1.0488	1792	26%	0.2727	466
Ethylene	C_2H_4	0.974	1613	-	-	-
Propane	C_3H_8	1.5624	2592	5%	0.0781	130
Propylene	C_3H_6	1.45	2336	-	-	-
N-Butane	C_4H_{10}	2.0666	3373	2%	0.0613	67
Iso-Butane	C_4H_{10}	2.0666	3365	-	-	-
N-Pentane	C_5H_{12}	2.4872	4017	1%	0.0249	40
Iso-Pentane	C_5H_{12}	2.4872	4007	-	-	-
Hyrogen Sulfide	H_2S	1.1899	646	2%	0.0238	13
Carbon Dioxide	CO_2	1.5284	-	3%	0.0459	-
Nitrogen	N_2	0.9717	-	-	-	-
Oxygen	O_2	1.1053	-	-	-	-
Water Vapor	H_2O	0.6215	-	-	-	-
			Total	100%	0.8447	1334

$$FUELI1 = 0.8447 * \left(\frac{1327}{1334}\right)^2 = 0.84$$

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Installation Requirements

A main filter must be installed external to the MicroTurbine. A pressure regulator is usually required to maintain steady fuel pressure at the MicroTurbine inlet. The inlet pressure must remain at or above the minimum requirement during load and during cold (maximum fuel flow) conditions.

Fuel Option Kits available from Capstone provide the necessary manual fuel isolation valve, external fuel filter, purge valve and pressure regulator needed for a standard installation. Contact Capstone Technical Support for details on the Fuel Option kits specified below:

Part Number	Description	Remarks
507849-1XX	High Pressure External Gaseous Fuel Kit	Pressure regulator, gauge, manual shutoff valve and filtration
507849-2XX	Low Pressure External Gaseous Fuel Kit	Manual shutoff valve and filtration
508604-1XX	Sour Gas External Gaseous Fuel Kit	Pressure regulator, gauge, manual shutoff valve and filtration

Commissioning the System

The MicroTurbine inlet pressure requirements are defined in Tables 3 and 4. The inlet fuel gas supply must be maintained at minimum pressure at the maximum flow rate for proper operation. An adequate fuel supply pressure without pressure loss at high flow rates is ESSENTIAL for proper MicroTurbine operation.

Due to inlet pressure requirements, many applications require external compressors. Capstone can provide optional Fuel Gas Booster (FGB) kits that can be operated using MicroTurbine power for Stand Alone installations. Refer to the Capstone Fuel Gas Booster Installation Instructions (410016) for details.

Special Biogas fuel processing considerations in meeting liquid fuel particulate requirements can be found in the Landfill/Digester Biogas Gas Usage (Biogas) Application Guide (480002).

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Table 3. Gaseous Fuel Supply Pressure and Temperature Requirements

System	Supply Pressure in kPa (Gage (psig))		Supply Temperature in °C (°F)	
	LSL	USL	LSL	USL
C30 HP	379 (55) (Note 2)	414 (60) (Notes 2,3)	Note (4)	50 (122)
C30 LP	1.4 (0.20)	103 (15)	Note (4)	50 (122)
C30 SG	379 (55) (Note 2)	414 (60) (Note 2)	Note (4)	50 (122)
C30 L/DG	(Note 3)	(Note 3)	Note (4)	50 (122)
C60 HP	517 (75)	552 (80)	Note (4)	50 (122)
C60 HP/ ICHP	517 (75)	552 (80)	Note (4)	50 (122)
C60 LP (Note 1)	3.4 (0.50)	103 (10)	Note (4)	50 (122)
C60 LP/ ICHP (Note 1)	3.4 (0.50)	103 (10)	Note (4)	50 (122)

Notes:

(1) Low pressure gas can be used when C60 HP, C60 HP ICHP is integrated with Capstone Integrated Fuel System Optional Accessory.

(2) Fuels with Calorific Value greater than Natural Gas Range or Sour Natural Gas Range may require lower inlet pressures, down to 310 kPa (45 psig).

(3) This item is dependent upon the fuel Calorific Value as noted in Table 4.

(4) This value must be the highest of 0 °C (32 °F), or 10 °C (18 °F) above the fuel dew point temperature at the Fuel Supply Pressure Maximum noted in this table.

Table 4. L/DG Fuel Supply Pressure Requirements

Calorific Value (HHV) [MJ/m^3 (Btu/ft^3)]		Supply Pressure [kPa Gage (psig)]	
LSL	USL	LSL	USL
26.1 (700)	38.4 (1,030)	345 (50)	379 (55)
22.4 (600)	26.1 (700)	345 (50)	414 (60)
18.6 (500)	22.4 (600)	379 (55)	448 (65)
16.8 (450)	18.6 (500)	414 (60)	483 (70)
14.9 (400)	16.8 (450)	448 (65)	517 (75)
12.1 (325)	14.9 (400)	483 (70)	552 (80)

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Diagnostic Faults

Detailed explanation of all gas-related diagnostic faults is available in the Model C30 Troubleshooting Guide (430000), and Model C60 Troubleshooting Guide (430013). Some of the more common fuel system faults that may appear are listed below.

Sensor Faults			
Fault No.	**Fault Description**	**SSL**	**Isolation Message**
3024	LOW FUEL PRESSURE	3	Internal Fault
3026	LOW FUEL AIR PRESSURE	3	Internal Fault
3027	HIGH FUEL AIR PRESSURE	3	Internal Fualt
3029	RFC AIR ASSIST FAILURE	3	Fuel Fault
3031	RFC LOW FUEL PRESSURE	3	Fuel Fault

Package Faults			
Fault No.	**Fault Description**	**SSL**	**Isolation Message**
5000	FUEL SUBSYSTEM	3	Internal Fault
5001	NO FUEL DEVICE	3	Internal Fault

Operational Faults			
Fault No.	**Fault Description**	**SSL**	**Isolation Message**
6006	FAIL TO LIGHT	3	Internal Fault
6009	OVERTEMP	3	Internal Fault
6010	HIOVERTEMP	3	Internal Fault
6011	FLAMEOUT_START	3	Internal Fault
6012	FLAMEOUT_LOAD	3	Internal Fault

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Maintenance Items

Scheduled maintenance intervals for component parts are summarized in the MicroTurbine Standard Maintenance Schedule (440000).

Related Documentation

The following table lists applicable Capstone documentation.

Document No.	Document Title
400000	Capstone MicroTurbine Users Manual
410002	Capstone MicroTurbine Fuel Requirements Technical Reference
410012	Capstone Components Description Technical Reference
410013	Capstone Remote Monitoring System (Users Edition) Technical Reference
410016	Capstone Fuel Gas Booster Installation Instructions
430000	Capstone Model C30 Troubleshooting Guide
430002	Capstone Model C30 Service Manual
430013	Capstone Model C60 Troubleshooting Guide
430017	Capstone Model C60 Service Manual
440000	Capstone MicroTurbine Standard Maintenance Schedule Work Instructions
480002	Capstone Landfill/Digester Gas Usage (Biogas) Application Guide

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Capstone Technical Information

If questions arise regarding Natural Gas operation for your Capstone MicroTurbine, please contact Capstone Turbine Technical Support for assistance and information.

Capstone Technical Support
Toll Free Telephone: (877) 282-8966
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